CHAPTER 1

The Belgian sandy beach ecosystem – a review

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Abstract

This paper provides a comprehensive overview of the available knowledge on sedimentology and hydrodynamics and five major ecosystem components - microphytobenthos, vascular plants, terrestrial arthropods, zoobenthos (macrobenthos, meiobenthos, hyperbenthos and epibenthos) and avifauna - of Belgian sandy beaches (from foredunes to foreshore). An ecosystem overview is presented for this specific geographically delimited shoreline, instead of dealing with a single component only.

Belgian beaches are (ultra-)dissipative, macrotidal and wide beaches with a cross-shore average median grain size of 160-380 µm. Sediment becomes coarser, slopes steeper, tidal range smaller towards the east. Especially eastern beaches have been reshaped frequently through human action (e.g. beach nourishment). Belgian beaches are characterised by the presence of highly adapted organisms. It is demonstrated that even a highly recreational and heavily populated coastline like the Belgian coast provides valuable yet threatened habitats to several beach-dependent species, which may reach high numbers. Vascular plants of the drift line, dry beach and embryonic dunes are mostly short-lived and thalassochorous. Most common species are sea rocket (*Cakile maritima*), prickly saltwort (*Salsola kali* subsp. *kali*) and sea sandwort (*Honckenya peploides*). Terrestrial arthropods inhabiting the same general area are highly diverse, comprising halobiontic, halophilous and haloxene species. Prominent members of this fauna are sandhopper (*Talitrus saltator*) and dipterans (flies). Microphytobenthos is an important primary producer on Belgian beaches, mainly consisting of diatoms. Very little is known about this group of organisms. Belgian beaches also have a specific zoobenthic fauna in both meiofauna and macrofauna, e.g. the typical upper intertidal *Scolelepis squamata-Eurydice pulchra* community. Also epi- and hyperbenthic animals depend on the beach, e.g. as nursery grounds. Nowadays no nesting of birds occurs on the beach itself. Nevertheless, Belgian beaches are important for resting and foraging (e.g. sanderling *Calidris alba*). Little is know about biological interactions on Belgian beaches. Human actions associated with several aspects of recreation, beach management and fisheries, are endangering all the discussed biota, and are specified.

Keywords: sandy beach ecosystem, microphytobenthos, vascular plants, terrestrial arthropods, zoobenthos, avifauna

Introduction

Belgian beaches are strongly developed for recreational needs and mostly have concrete dykes separating the littoral part of the beach from the adjacent dune areas. Thus, they may seem biologically poor and resistant to human activity. The ecosystem of Belgian beaches has been heavily impacted by human actions. Both negative and positive effects on the sandy beach ecosystem have been observed (Speybroeck *et al.,* 2005). Apart from beach cleaning (removal of strand line material), profiling of the dry beach, implant of brushwood hedges and trampling, beach nourishment strongly impacted Belgian beaches. Trying to draw a holistic ecosystem picture, this paper aims at presenting the biological values of Belgian sandy beaches based on literature. Thus, knowledge from quite different fields of research is compiled and put into an ecosystem perspective. The biodiversity of Belgian sandy beaches will be discussed within delimited zones along the cross-shore gradient. Anthropogenic pressures on this ecosystem will be discussed. Concerning the ecological impact of beach nourishment, the reader is referred to Speybroeck *et al.* (2006).

We apply a conventional zonation scheme: (1) supralittoral zone above the high water line but influenced by sea water): embryonic dunes, dry beach and strand line; (2) littoral zone (= intertidal zone): between high water and low water lines; (3) infralittoral zone, here only the foreshore zone, i.e. defined as the seaward continuation of the beach profile until a depth of 4 m below MLWS level. The biological aspects of these zones will be limited to five major ecosystem components: (1) microphytobenthos (consisting of photosynthetic micro-organisms; eukaryotic algae and cyanobacteria); (2) terrestrial arthropods (arthropods of the strand line, the dry beach and the embryonic dunes); (3) vascular plants; (4) zoobenthos (macrobenthos, meiobenthos, hyperbenthos and epibenthos) and (5) avifauna (birds). Biota of the beach ecosystem are strongly determined by its physical environment, thus hydrodynamics and sedimentology were also taken into account.

The physical environment

THE BELGIAN COAST

The Belgian coast is a 65 km, southwest to northeast directed, rectilinear sandy coastline which passes to the east, in the Netherlands, into the 5 km estuary of the Westerschelde river (Figure 1). Belgian beaches display a macrotidal, semi-diurnal tidal regime. The average amplitude at spring tide varies from about 5 m at the French border and descends until 4.3 m towards the east (Fremout, 2002). The climate of winds and waves is dominated by a southwest to northwest direction. The southwest/northeast directed flood current (> 1 m/s) is dominant, and gives rise to a residual drift towards the northeast. The dominant southwestern winds also induce a northeastern aeolian drift. Storm winds from the northwest until the north predominantly cause coastal erosion (Anonymous, 1993). Close to the shore, average significant wave heights of 0.5 to 1 metres occur with a period of 3.5 to 4.5 seconds (Anonymous, 1993).

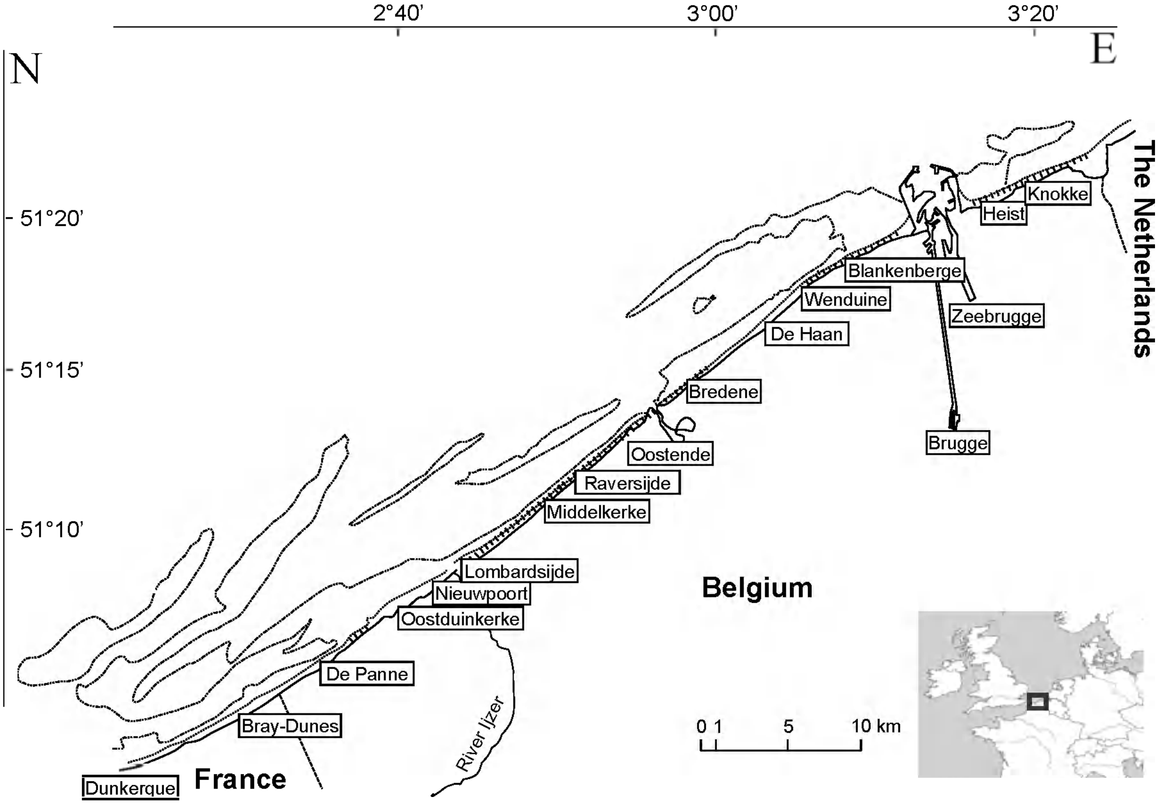


Figure 1. The Belgian coast with indication of municipalities.

The slope of the intertidal zone varies between 0.8 and 2.5 % (calculations based on digital field data of the VITO - Flemish Institute for Technological Research) and in general increases towards the east (Fig. 2). The width of the intertidal zone varies from 200 to 500 metres, and decreases towards the east. The broad, intertidal zone along the western coast has a slope between 1 and 1.3 % and is characterized by a typical morphology of runnels and ridges, breached by outlets, which carry off the water at the ebb tide. Beaches further to the east have a steeper slope (> 1.4 %) and their profile shows less relief. From Bredene to the east, the beach profile becomes more irregular. In the past, these beaches were subjected to the highest coastal erosion and they have been nourished frequently.

Sand on Belgian beaches has an average median grain size of 200-220 μm (cross-shore average of median grain size ranging from 160 μm to 380 μm – data from VITO 2001). The sediment becomes coarser from west to east. From the French-Belgian border to Raversijde this coarsening is rather uniform, while further east the trend is less straightforward: the highest oscillations are situated east of Heist, at least partially attributable to a long history of beach nourishment (De Moor, 2006). Cross-shore an overall, slight increase of about 70 μm in grain size can be observed in the direction of the hinterland. Belgian beach sand mainly consists of quartz (De Moor and Dedecker, 1981). The beach sediment includes a calcareous component due to the presence of shell hash, which locally may cause significantly elevated grain size values. In general the beach sediment does not contain significant levels of fines, apart from some local enrichment in runnels (Degraer *et al.*, 2003a).

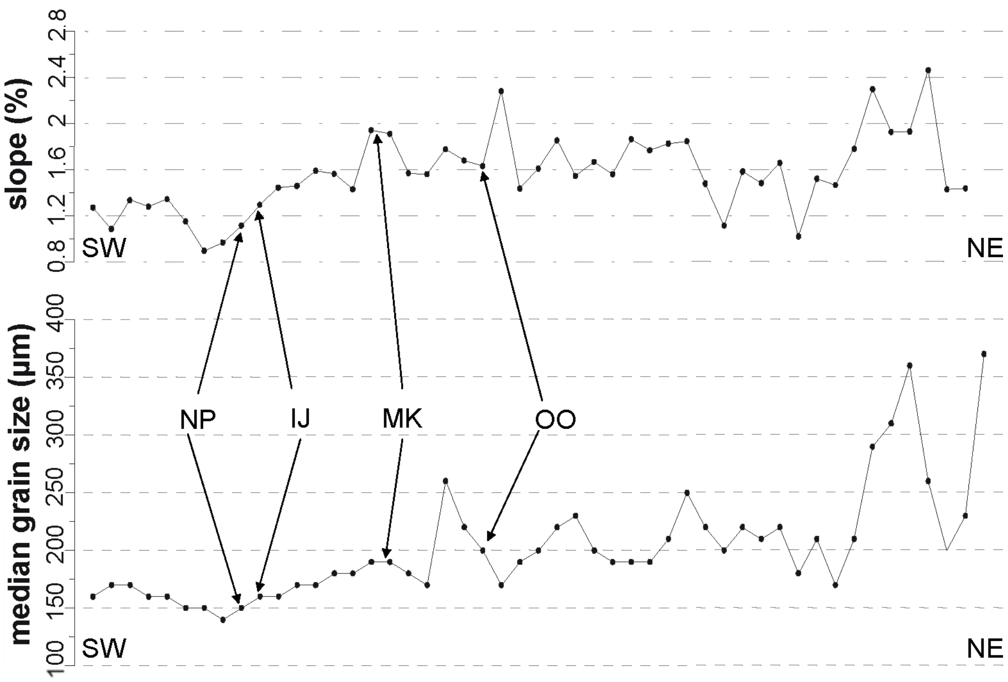


Figure 2. Intertidal slope and median grain size near low water line of Belgian beaches (from southwest to northeast = French to Dutch border) (Data source: VITO 2001). Western localities at the left, eastern ones at the right. Indicated are beaches sampled within this thesis (Chapters 3-4; NP = Nieuwpoort; IJ = Ijzermonding; MK = Middelkerke; OO = Oostende).

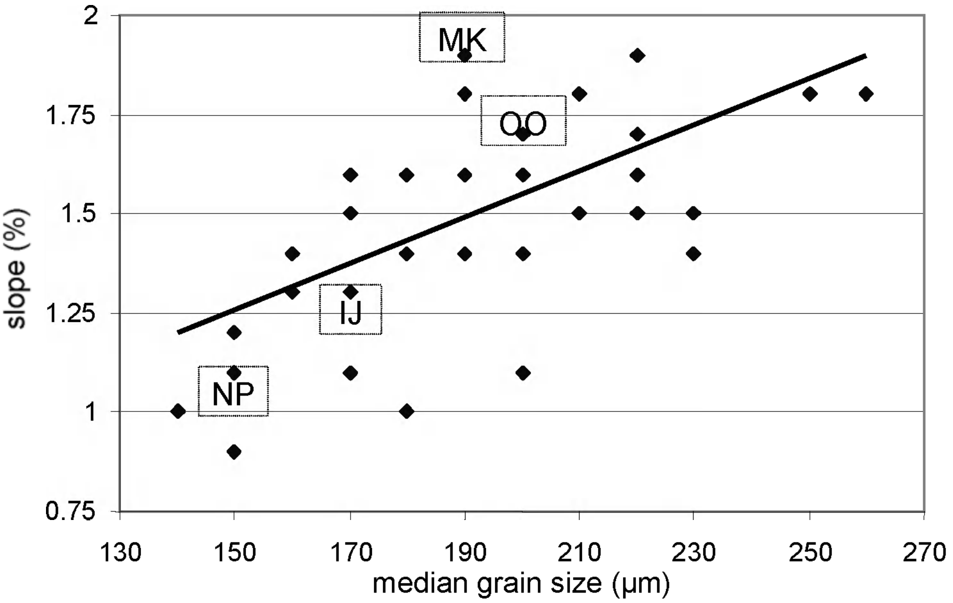


Figure 3. Slope (%) versus median grain size (µm) on Belgian beaches. Indicated are beaches sampled within this thesis (Chapters 3-4; NP = Nieuwpoort; IJ = Ijzermonding; MK = Middelkerke; OO = Oostende).

Based on sequential beach profiling, De Moor (1979, 1988, 1993, 2006) argued that a natural cycle explains the periodical behaviour of erosion and accretion on beaches. It remains however unresolved whether long term differences are due to slowly moving waves of sand (Verhagen, 1989) or to changes in wave energy.

Along the western coast, beaches are mostly stable and accreting. The beach sedimentology, further east until Oostende, does not evolve in accordance with any clear trend, while trends are variable east of Oostende. These beaches are subjected to severe human impact (management measures like nourishment, reprofiling, ...). The foot of the coastal dunes is accreting along most of the Belgian coast, due to the consistent implant of brushwood hedges (De Wolf, 2002). De Wolf (2002) indicates that the beaches of Bredene to Wenduine, the beach immediately in the lee of the eastern harbour wall of Zeebrugge and the beaches in front of dykes with a rather pushed-forward position (Knokke), normally are erosive. Beaches further east (towards the Dutch border) are more or less stable, but at the mouth of the Zwin erosion occurs.

Based on tidal amplitude, modal breakers height, wave period and sediment characteristics, Belgian sandy beaches are classified as dissipative to ultradissipative beaches (according to Short, 1996, 1999), albeit with a slight decrease in their dissipative nature, from west to east (Fig. 4). This implies that processes related to the swash and surf zone will mainly dominate the morphodynamics of the upper intertidal zone with possible formation of a spring high tide ridge. The morphodynamical behaviour of the middle and lower intertidal zone is mainly related to the surf zone and dissipating waves. Swash processes can be locally significant and may cause formation of ridges. Tidal currents are of importance in the infralittoral zone. Morphodynamic classification allows correlations with ecosystem components (e.g. distribution of macrobenthic communities, Degraer *et al.*, 2003a).

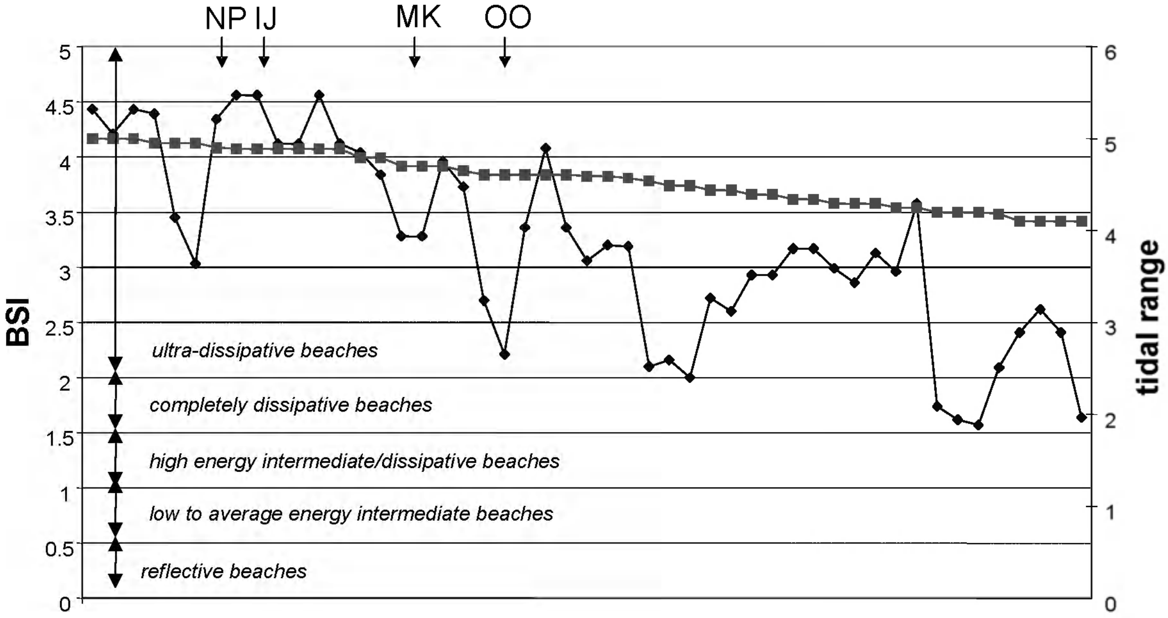


Figure 4. Morphodynamics (Beach state index (BSI) – McLachlan *et al.*, 1993) and mean amplitude of spring tidal range (m). Southwesternmost localities are at the left, northeasternmost ones at the right of the graph. Indicated are beaches sampled within this thesis (Chapters 3-4; NP = Nieuwpoort; IJ = Ijzermonding; MK = Middelkerke; OO = Oostende).

GENERAL FEATURES OF BEACHES SAMPLED WITHIN THIS THESIS RESEARCH (CHAPTERS 3 AND 4)

Based on previous knowledge, we selected 8 cross-shore transects for the investigation of population dynamics of macrobenthic key species (Fig. 5). The same samples were used for research on both *Scolelepis squamata* (Chapter 3) as the *Bathyporeia* species (Chapter 4). The transects were sampled monthly from October 2003 until October 2004, January 2004 excluded. Sampling started each time at high tide and continued until the low tide level was reached, taking a sample every half hour just above the upper swash limit. In order to minimise differences in tidal range among sampling months, sampling dates related to a fixed point in the lunar spring tide-neap tide cycle. Each sample involved a 0.1026 m² rectangle being dug out to a depth of 20 cm and sieved over a sieve with a 1 mm mesh width. An additional sample was taken for analysis of sedimentology. Elevation of sampling stations and the entire beach profile were measured using a leveller and corroborated afterwards with the output of the M2 tidal reduction model (Coastal Division of the Agency of Maritime and Coastal Services).

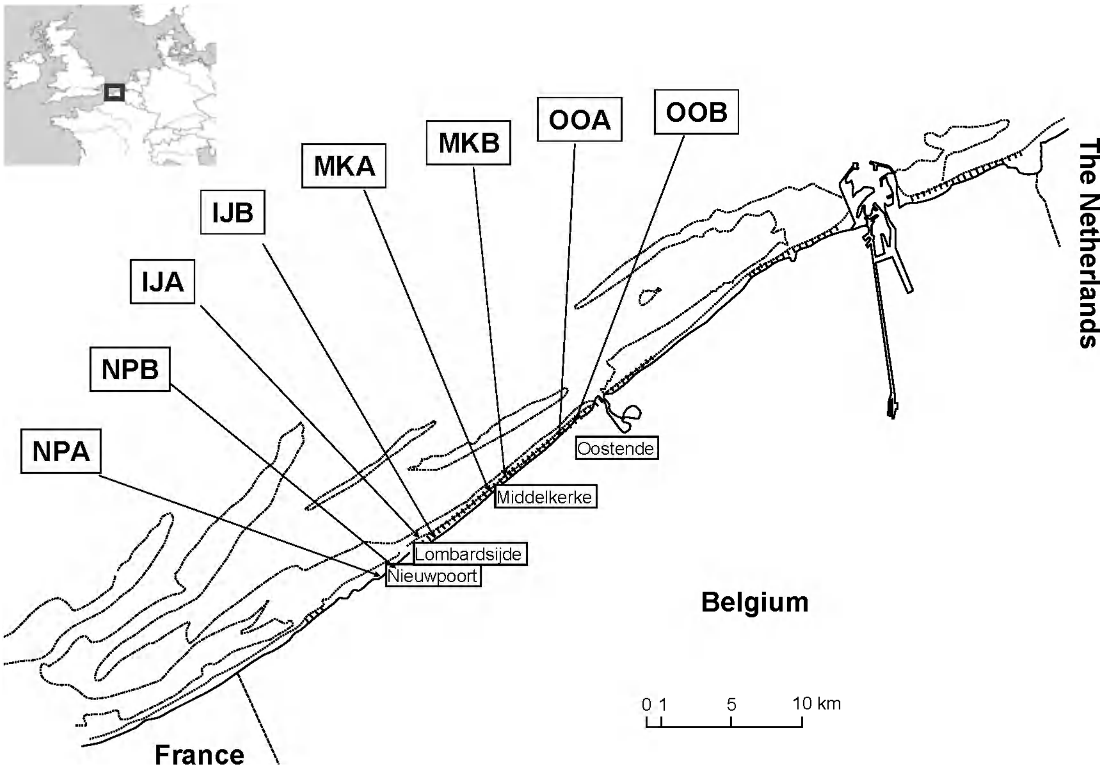
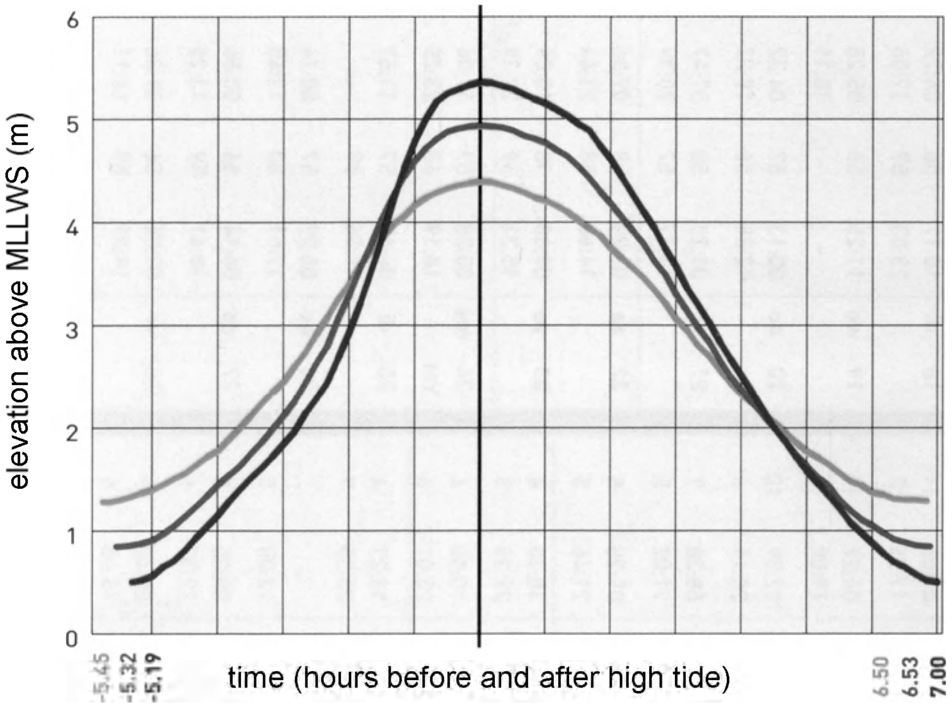


Figure 5. Location of sampled transects along the Belgian coast; NP = Nieuwpoort-Bad, IJZ = beach of Flemish nature reserve "Ijzermonding", MK = Middelkerke-Bad, OO = Oostende-Bad; capitals A and B are to identify each of the two transects within the same beach.

All sampled beaches are wide, macrotidal beaches with a sampled intertidal section ranging from about 170 to over 200 m in width and an average spring tide tidal range ranging more or less from 4.5 to 4.7 meter. Beach slope was weak (0.75-1.15°). Sediment analysis showed median grain size to range from 171 to 347 µm and the sediment to be well to moderately well sorted (SD of median grain size (µm) = 1.29-1.58). With a beach index (BI

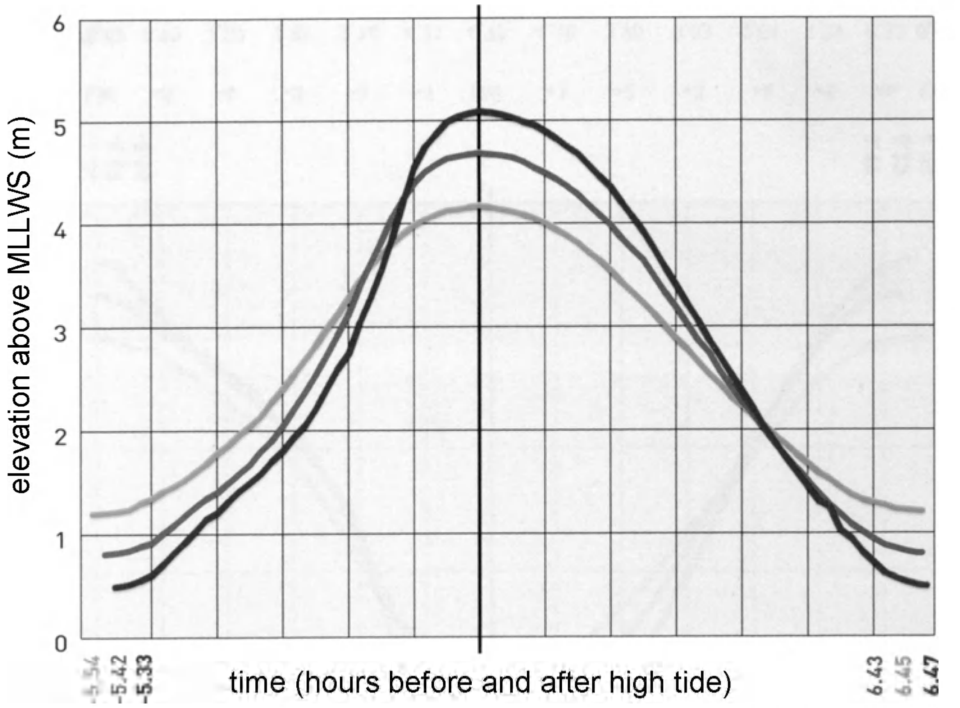
– McLachlan and Dorvlo, 2005) of 2.7 to 3.0, the morphodynamic type of all four beaches is clearly dissipative, in concordance to Degraer *et al.* (2003). Western transects have, however, higher beach index values (BI = 2.95 ± 0.03 SD) than eastern ones (BI = 2.75 ± 0.03 SD) (Mann-Whitney U Test: Z = 2.12; p = 0.03), suggesting eastern transects to be a little less dissipative.

In the next graphs, tidal curves and beach profiles are given for the most southwestern (Nieuwpoort) and most northeastern (Oostende) of the four sampled beaches (Figs. 6-9).



LW	-5	-4	-3	-2	-1	HW	+1	+2	+3	+4	+5	+6	LW	
0,49	0,55	1,14	1,83	2,92	4,78	**5,35**	5,14	4,60	3,56	2,50	1,57	0,87	**0,49**	mean spring tide
0,84	0,90	1,44	2,11	3,29	4,59	**4,93**	4,76	4,17	3,29	2,36	1,62	1,04	**0,84**	mean tide
1,28	1,39	1,77	2,44	3,39	4,16	**4,39**	4,20	3,74	3,05	2,32	1,76	1,36	**1,28**	mean neap tide

Figure 6. Tidal curves of Nieuwpoort beach (NP). Upper (darkest) line represents spring tidal curve, lower (palest) line represents neap tidal curve, mean tidal curve runs in between them.



LW	-5	-4	-3	-2	-1	HW	+1	+2	+3	+4	+5	+6	LW	
0,49	0,61	1,21	1,81	2,75	4,55	**5,09**	4,90	4,36	3,40	2,38	1,45	0,72	**0,49**	mean spring tide
0,81	0,92	1,41	2,05	3,13	4,40	4,69	4,50	3,99	3,19	2,27	1,51	0,95	0,81	mean tide
1,21	1,35	1,79	2,41	3,29	3,99	4,18	4,01	3,55	2,89	2,24	1,68	1,30	1,21	mean neap tide

Figure 7. Tidal curves of Oostende beach (OO). Upper (darkest) line represents spring tidal curve, lower (palest) line represents neap tidal curve, mean tidal curve runs in between them.

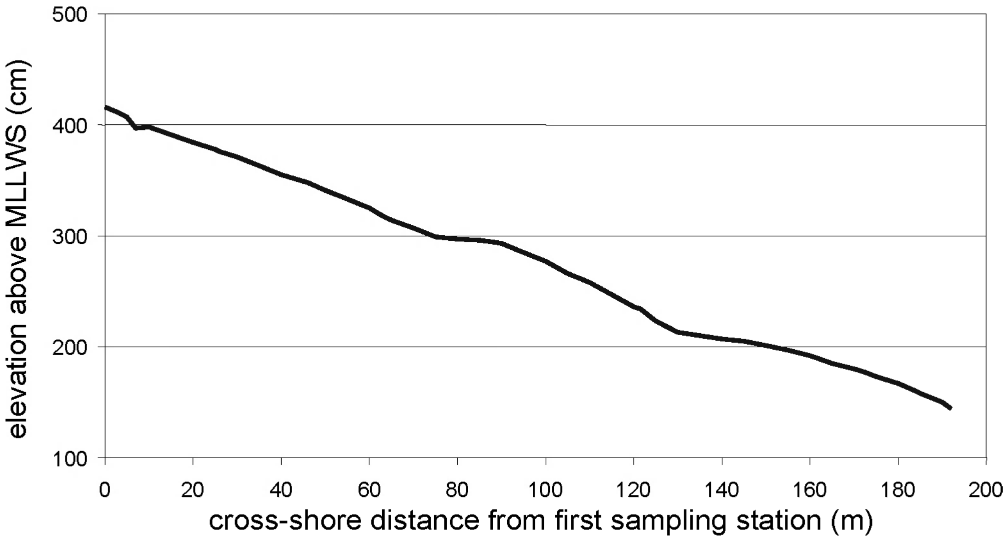


Figure 8. Sampled section of the intertidal beach profile of Nieuwpoort beach (NP) - October 2004.

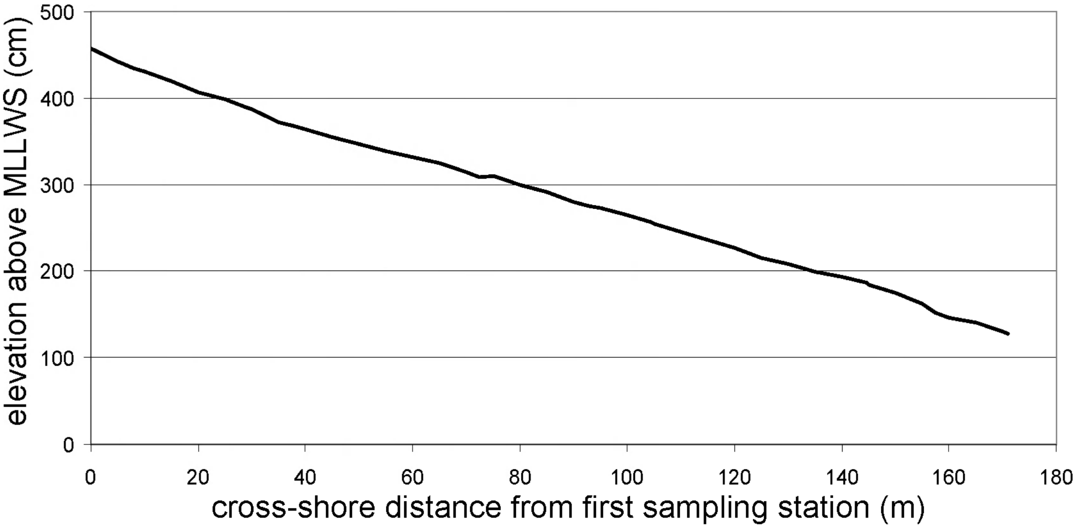


Figure 9. Sampled section of the intertidal beach profile of Oostende beach (OO) - October 2004.

Significant differences between transects were found in median grain size (Friedman Chi Square (N = 4, df = 6) = 22.39; $p < 0.01$). Western transects (IJA, IJB, NPA, NPB) exhibit lower median grain sizes, especially those from Nieuwpoort (NP; e.g. NPB: 192 ± 6 SD µm), whereas grain size on Middelkerke and Oostende beaches seems comparably larger (e.g. MKB: 268 ± 24 SD µm).

Minor quantities of fines (< 63 µm) were encountered in western transects (highest in NPB: 0.14 ± 1.00 SD % but at least 4x less in other western transects), but were usually completely absent from eastern transect sediment samples.

The biological environment

VASCULAR PLANTS

Vascular plants are limited to the Belgian supralittoral along the drift line, on dry beach and in embryonic dunes. Most species are short-lived and adapted to the dynamic nature of this biotope. In stable supralittoral areas perennial plant species can also settle (Provoost *et al.*, 2004; Van Landuyt *et al.*, 2004). Most species are dispersed by means of floating seeds that can resist seawater for a long time (i.e. thalassochory) and thus strand lines can easily be colonized (Rappé, 1996, 1997). The germinating plants benefit from the local nutrient enrichment and the temporary shelter of the strand line. A number of species naturally grows specifically in the supralittoral zone but their occurrence is not limited to natural locations; e.g. an important population of sea beet (*Beta vulgaris* ssp. *maritima*) is growing on the dyke, bordering the gully of the harbour of Nieuwpoort. All these taxa can be considered as tolerant to salty soils. Considering the ephemeral occurrence of many species, an accurate estimation of the population size would require surveys of several years.

The most common species along Belgian beaches is sea rocket (*Cakile maritima*), often accompanied by prickly saltwort (*Salsola kali* subsp. *kali*) and sea sandwort (*Honckenya peploides*). More rare are grassleaf orache (*Atriplex littoralis*) and sea beet (*Beta vulgaris* subsp. *maritima*) and only sporadically species such as frosted orache (*Atriplex laciniata*), yellow horned-poppy (*Glaucium flavum*) and Ray's knotgrass (*Polygonum oxyspermum* subsp. *raii*) can be found. The latter has a very limited distribution range in northwest Europe (Jalas and Suominen, 1979). Even though it has been mentioned for the first time only fairly recently (Rappé, 1984) Babington's orache (*Atriplex glabriuscula)* can regularly be observed on most of the Belgian beaches. Sea-kale (*Crambe maritima*) and rock samphire (*Crithmum maritimum*) are much rarer (Rappé and Goetghebeur, 1975; Rappé, 1989, 1996; Van Landuyt *et al.*, 2006). Sea couch (*Elymus farctus* subsp*. boreoatlanticus*), often within stands of *Cakile*, initiates the development of primary dunes. When the input of sand is sufficient, the embryonic dunes will grow and the soil salinity will gradually decrease to brackish or fresh. At this stage, marram (*Ammophila arenaria*) starts dominating and becomes the dune forming species. Locally, foredune species, such as sea holly (*Eryngium maritimum*), sea bindweed (*Calystegia soldanella*) and sea spurge (*Euphorbia paralias*), can be found in these embryonic dunes (Rappé *et al.*, 1996; Provoost *et al.*, 2004). On sheltered, gently sloping beaches, where silt accumulation takes place (so called 'green beach'), the flora is gradually enriched with salt marsh species e.g. annual sea-blite (*Suaeda maritima*), glasswort (*Salicornia* spp.) or sea-milkwort (*Glaux maritima*). Along the Belgian coast, this only occurs at the "Baai van Heist", which harbours the richest beach vegetation of Belgium (Devos *et al.*, 1995; Cosyns *et al.*, 1999; Van Landuyt *et al.*, 2000). This seems to surprise, given the more erosive nature of beaches east of Zeebrugge, yet might be attributed to nature management of the specific site and special hydrodynamic conditions adjacent to harbour walls. All typical species of the supralittoral zone are classified on the Red List as rare to (highly) endangered (Van Landuyt *et al.*, 2006). Apart from the impact of beach nourishment (burial and sediment budget disturbance), supralittoral vascular plants are affected by a number of human impacts. Recreation and mechanical beach cleaning can be considered as the most important threat to supralittoral vegetation and the development of embryonic dunes (Provoost *et al.*, 1996, 2004). Brushwood hedges, planted for coastal defence reasons, offer some shelter to these disturbances and are therefore a preferred habitat for species of the dry beach.

TERRESTRIAL ARTHROPODS

The arthropod fauna of strand line, dry beach and embryonic dunes contains a diverse range of species adapted to salty environments to a varying degree: (1) halobiontic species which can only live in salty environments, (2) halophilous species, living in both salty and fresh water environments, and (3) haloxene species which are rather incidental visitors. Many species depend on stranded material. The European arthropods living in and near this material have been studied rather intensively (Backlund, 1945; Ardö, 1957; Tsacas, 1959; Remmert, 1964; Egglishaw, 1959; Caussanel, 1970; Cheng, 1976; Dobson, 1976; Doyen, 1976; Moore and Legner, 1976; Louis, 1977; Bergerard, 1989). The wrack contains mainly kelps and brown algae, in which typical decomposers (mainly flies) and their predators and parasites are found. Common dune species (isopods, spiders and carabids) are often encountered in the wrack, especially if a natural connection between the dunes and the beach (still) exists (Maelfait, unpublished data). The sandhopper *Talitrus saltator* (Amphipoda, Talitridae) is a dominant species of the strand line (Lincoln, 1979) and plays an important role as primary comsumer of stranded dead plant and animal material (Robertson and Mann, 1980; Griffiths *et al.*, 1983; Stenton-Dozey and Griffiths, 1983; Adin and Riera, 2003). The species reaches high numbers on the beaches near the mouth of the river Ijzer and in the Flemish nature reserve "Baai van Heist" (Maelfait, unpublished data). During periods of spring tide, individuals migrate from the high water line to the frontal row of dunes, where consequently they can be found in high numbers (Maelfait, unpublished data). Predator mites (Gamasina), feeding on springtails (see below) and other invertebrates, play an important role in the ecosystem (Koehler *et al.*, 1995; Salmane, 2000). Certain species are restricted to the strand line (e.g. *Thinoseius* species; Egglishaw, 1959; Remmert, 1964), dry beach and/or embryonic dunes. Specialised species disappear if the beach dries up and the wrack quantity decreases. Detailed data on the distribution of predator mites along the Belgian coast are, however, unavailable. Beach-restricted spiders (Aranea) are absent on Belgian beaches. Sometimes Red List dune species can be found (Maelfait *et al.*, 1998). Furthermore, spiders can be found in the wrack due to anemohydrochory, i.e. winds bring them into coastal water and then they strand on the beach) (Palmen, 1944). The importance of this dispersal for the spider species remains unknown. On the dry beach, benthic springtails (Collembola) are known for their trophic relation with mycorrhiza (i.e. symbiosis of plants and fungi) of several plant species (e.g. creeping willow *Salix repens*) (Read, 1989). Because of the positive effect these mycorrhiza have on sediment stability, dispersal of mycorrhiza by springtails can affect sediment stability (Koehler *et al.*, 1995). Two species (*Folsomia sexoculata* and *Isotoma maritima*) only feed on rotting seaweeds (Janssens, 2002). However, due to their cryptic way of life, no further detailed ecological information is available on them. Fourteen beetle families (Coleoptera) have been recorded on Belgian beaches (Haghebaert, 1989). Most species rich families are Staphylinidae (thirty species) and Carabidae (twenty species) (Haghebaert, 1989). A total of 46 species were found on the strand line, of which 34 are true halobionts and 12 are halophilous or haloxene species. Most species were predators of e.g. sandhoppers (Bergerard, 1989), but grazers (e.g. *Bledius arenarius* and *B. subniger*) and parasites (e.g. *Aleochara* spp.) are also found. *Bledius* species play a key role in the strand line food web (Den Hollander and Van Etten, 1974; Steidle *et al.*, 1995). *Cafius xantholoma* is the most common rove beetle of Belgian beaches (Haghebaert, 1989). The predatory ground beetles and tiger beetles (Carabidae and Cicindelidae) are adapted to life on sandy and dynamic substrates (Turin, 2000) (i.e. psammophilous beetles with digging legs or long legs to counter overheating) and they are halobiontic or halophilous species. *Cicindela maritima* and *Bradycellus distinctus* are halophilous species that are mainly found on the dry beach and the foredunes (Turin, 2000). *Amara convexiuscula* and *Bembidion normannum* can be abundant underneath wrack (Turin, 2000). Desender (2004) provides an overview of the beach and dune carabid and cicindelid beetles of the Belgian coast. Very specific Diptera (flies and mosquitoes) are restricted to the supralittoral zone and they form the most abundant group of beach insects. Their larvae feed on the organic matter of the strand line (Ardö, 1957; Tsacas, 1959). After minor attention in the past (Meunier, 1898; Villeneuve, 1903; Bequaert, 1913; Bequaert and Goetghebuer, 1913; Goetghebuer, 1928, 1934, 1942), a thorough inventory of the Belgian dipteran fauna started around 1980 (Grootaert and Pollet, 1988; Grootaert, 1989; Grootaert and Pollet 1989). More ecologically oriented studies followed (Pollet and Grootaert, 1994, 1995, 1996). A summary can be found in Grootaert and Pollet (2004a). *Chersodromia* spp. (Hybotidae) are tiny flies whose larvae live in the burrows of sandhoppers (Tsacas, 1959). Prior to 1980, *Chersodromia hirta* was rather common but nowadays the species is threatened (Grootaert, unpublished data). *Aphrosylus* species (Dolichopodidae) are typically encountered on hard substrates, while foraging individuals can also be found on beaches. Kelp flies (Coelopidae), of which the larvae feed on seaweeds, almost exclusively occur on stranded brown algae (Egglishaw, 1959, 1961; Dobson, 1974). They may form an important food source for wading birds (Smit and Wolff, 1981). No typical fly species are found on the dry beach, even though species of the foredunes can be found there temporarily (Pollet, 2000; Pollet et al., 2004).

The arthropods of Belgian beaches are threatened by excessive recreation and systematic removal of wrack on most beaches, thus blocking the development of embryonic dunes. Examples are a negative correlation between trampling and the abundance of *Talitrus saltator* (Weslawski *et al.*, 2000) and rareness of kelp flies due to beach cleaning (Grootaert, unpublished data). The more dominant species (with exception of mites) are listed in table 1. This table is based on a sampling of ten beaches (Speybroeck *et al.*, 2005). Of the species caught as more than ten individuals, the total number caught and the number of beaches on which they were observed (frequency) are given. Besides the amphipod *Talitrus saltator*, a number of fly and beetle species are the most typical fauna elements.

Table 1. Terrestrial arthropods frequently found on 10 Belgian beaches (Speybroeck *et al.*, 2005). See text for details.

	family	species	number	frequency
Araneae	Erigonidae	*Erigone atra*	13	6
Araneae	Linyphiidae	*Tenuiphantes tenuis*	31	6
Araneae	Linyphiidae	*Stemonyphantes lineatus*	17	3
Araneae	Linyphiidae	*Bathyphantes gracilis*	15	4
Araneae	Linyphiidae	*Oedothorax fuscus*	11	6
Coleoptera	Anthicidae	*Anthicus bimaculatus*	48	8
Coleoptera	Carabidae	*Calathus mollis*	50	8
Coleoptera	Carabidae	*Dicheirotrichus gustavii*	40	1
Coleoptera	Carabidae	*Demetrias monostigma*	15	5
Coleoptera	Carabidae	*Harpalus tardus*	11	6
Coleoptera	Chrysomelidae	*Psylloides marcida*	59	7
Coleoptera	Chrysomelidae	*Aphtoma euphorbiae*	17	8
Coleoptera	Chrysomelidae	*Longitarsus anchusae*	13	7
Coleoptera	Curculionidae	*Philopedon plagiatus*	127	6
Coleoptera	Curculionidae	*Otiorrhynus atroapterus*	23	7
Coleoptera	Histeridae	*Hypocaccus metallicus*	10	6
Coleoptera	Histeridae	*Baeckmanniolus maritimus*	10	3
Coleoptera	Hydraenidae	*Helephorus guttulus*	26	7
Coleoptera	Hydrophilidae	*Cercyon littoralis*	14	5
Coleoptera	Scarabaeidae	*Aegialia arenaria*	175	7
Coleoptera	Staphylinidae	*Bledius (Cotysops) fergussoni*	47	1
Coleoptera	Staphylinidae	*Diglotta mersa*	45	4
Coleoptera	Staphylinidae	*Bledius (Cotysops) subniger*	42	4
Coleoptera	Staphylinidae	*Atheta (Mocyta) fungi*	37	8
Coleoptera	Staphylinidae	*Anotylus sculpturatus*	28	5
Coleoptera	Staphylinidae	*Anotylus (Oxytelops) tetracarinatus*	26	5
Coleoptera	Staphylinidae	*Drusilla canaliculata*	21	2
Coleoptera	Staphylinidae	*Anotylus (Styloxis) rugosus*	20	5
Coleoptera	Staphylinidae	*Coprophilus striatulus*	19	5
Coleoptera	Staphylinidae	*Xantholinus linearis*	15	4
Coleoptera	Staphylinidae	*Cafius xantholoma*	12	2
Coleoptera	Staphylinidae	*Aleochara (Coprochara) bipustulata*	11	3
Coleoptera	Staphylinidae	*Lestera sicula heeri*	10	2
Coleoptera	Tenebrionidae	*Phaleria cadaverina*	190	6
Collembola	Isotomuridae	*Isotoma caerulea*	40	2
Crustacea (Amphipoda)	Talitridae	*Talitrus saltator*	4581	10
Crustacea (Oniscoidea)	Porcellionidae	*Porcellio scaber*	115	8
Diptera	Anthomyiidae	*Fucellia maritima*	9710	10
Diptera	Anthomyiidae	*Fucellia tergina*	1028	10
Diptera	Canacidae	*Canace nasica*	14	4
Diptera	Dolichopodidae	*Aphrosylus celtiber*	31	4
Diptera	Dolichopodidae	*Sciapus maritimus*	22	3
Diptera	Empididae	*Hilara lundbecki*	16	3
Diptera	Ephydridae	*Scatella lutosa*	160	4
Diptera	Ephydridae	*Hydrellia obscura*	18	4
Diptera	Ephydridae	*Scatella tenuicosta*	13	4
Diptera	Ephydridae	*Hecamede albicans*	11	3
Diptera	Helcomyzidae	*Helcomyza ustulata*	392	9

Diptera	Helcomyzidae	*Heterochila buccata*	16	4
Diptera	Hybotidae	*Chersodromia incana*	245	4
Diptera	Hybotidae	*Chersodromia hirta*	177	5
Diptera	Hybotidae	*Tachydromia sabulosa*	26	3
Diptera	Hybotidae	*Platypalpus strigifrons*	23	8
Diptera	Sphaeroceridae	*Copromyza equina*	491	10
Diptera	Sphaeroceridae	*Thoracochaeta zosterae*	21	8
Diptera	Sphaeroceridae	*Opacifrons septentrionalis*	13	7
Diptera	Sphaeroceridae	*Spelobia (Spelobia) clunipes*	13	6
Diptera	Sphaeroceridae	*Leptocera (Leptocera) nigra*	12	5
Diptera	Sphaeroceridae	*Coproica vagans*	11	6
Diptera	Sphaeroceridae	*Opacifrons humida*	11	4
Diptera	Sphaeroceridae	*Borborillus nitidifrons*	10	5
Diptera	Tethinidae	*Tethina illota*	690	10
Diptera	Tethinidae	*Rhicnoessa grisea*	197	9
Diptera	Tethinidae	*Tethina albosetulosa*	136	9
Lepidoptera	Noctuidae	*Autographa gamma*	16	6

MICROPHYTOBENTHOS

For Belgian beaches, only preliminary data on microphytobenthos are available: in total about 120 species have been reported (Van der Ben, 1973; Blondeel, 1996). Microphytobenthos (eukaryote algae and Cyanobacteria) in intertidal sediments is usually dominated by diatoms but dense populations of Cyanobacteria, dinoflagellates, euglenoids, Crypto- and Chrysophyta may occur (MacIntyre *et al.* 1996, Barranguet *et al.* 1997, Noffke and Krumbein 1999). The microphytobenthos is the main primary producer in intertidal areas and contributes substantially to the biomass and primary production in the water column in shallow coastal areas and estuaries (de Jonge and van Beusekom 1995, MacIntyre et *al.* 1996). Sandy sediments are mostly dominated by attached life forms (epipsammon), while free-living forms (epipelon and tychoplankton) are dominant in sediments rich in fines. A strong relationship exists between sedimentological characteristics like stability, porosity, permeability, penetration of light and dissolved gasses and water content on one hand and the biological activity of the microphytobenthos in sediments on the other. Thus sediment type largely determines the distribution of the microphytobenthos (Sabbe, 1997; Paterson and Hagerthey, 2001).

Current knowledge on the diversity, structure and dynamics of sandy beach microphytobenthos is limited (Meadows and Anderson, 1968; Steele and Baird, 1968; Amspoker, 1977; Asmus and Bauerfeind, 1994; Fernandez-Leborans and Fernandez-Fernandez, 2002). Species richness in intertidal sediments may nevertheless be high: e.g. on tidal flats in the Westerschelde estuary about 200 benthic diatom species were encountered (Sabbe, 1997). While strong indications exist of microphytobenthos being an important food source for micro-, meio- and macrobenthos (e.g. Sundbäck and Persson, 1981; Middelburg *et al.,* 2000; Granéli and Turner, 2002; Moens *et al.,* 2002), until today little is known of the qualitative and quantitative role of the microphytobenthos in sandy beach food webs. Specialised surf zone diatoms are mainly known from the southern hemisphere (Campbell, 1996). The same species occur in Europe (and along the Belgian coast:

Blondeel, 1996), but nothing is known about their quantitative importance and their specific life history. Because of the high levels of turbidity in the infralittoral zone, little *in situ* primary production can be expected in sediments. Tychoplankton, plankton and resuspended microphytobenthos will play a major role here. At the moment, it remains unknown whether the foreshore contains specialised plankton communities (i.e. different from pelagic North Sea communities).

ZOOBENTHOS

Knowledge on intertidal meiofauna of Belgian beaches is limited (Gheskiere *et al.* 2002, 2004, 2006; Kotwicki *et al.*, 2005). At higher taxonomic level, in general 15 meiofauna taxa were recorded, Nematoda, Harpacticoida and Turbellaria being the dominant ones. On the beach of De Panne, average total meiofaunal densities increased from the upper littoral (56 ± 13 ind/10cm²) towards the lower littoral zone (3518 ± 540 ind/10cm²) (Gheskiere *et al.*, 2002). Nematode species richness increased from the upper littoral (8 ± 2 species) reaching a maximum around mid-tide level (34 ± 3 species). Three species associations were designated: dry beach (supralittoral, including typical marine, typical brackish as well as typical terrestrial free-living nematodes; *Rhabditis* sp. and *Axonolaimus helgolandicus*), upper intertidal (*Trissonchulus* sp., *Dichromadora hyalocheile* and *Theristus otoplanobius*) and lower intertidal (several species, among others *Odontophora phalarata, O. rectangula, Cyartonema elegans* and *Chaetonema riemanni*) (Gheskiere *et al.,* 2004).

Of the marine zoobenthos, the macrobenthos is best investigated. Like on most beaches worldwide (McLachlan and Jaramillo, 1995), polychaetes (bristle worms) and crustaceans dominate the Belgian sandy beach macrobenthos (Degraer *et al.*, 1999a; Degraer *et al.*, 2003a). Due to a relatively lower environmental stress on the ultradissipative beaches, the highest macrobenthic abundance and diversity are encountered on softly sloping, broad and fine grained beaches (Degraer *et al.*, 2003a).

More reflective beaches (east of Oostende) are clearly not as rich in species but they do harbour a number of rare species like the polychaetes *Hesionides arenaria* and *Ophelia rathkei* and the amphipod *Haustorius arenarius* (Degraer *et al.*, 2003a). Furthermore, a cross-shore gradient is distinguished with the upper littoral zone being inhabited by a species-poor, yet high density community. On Belgian beaches, this community is dominated by the polychaete *Scolelepis squamata*, the isopod *Eurydice pulchra* and two amphipods *Bathyporeia pilosa* and *B. sarsi* (Degraer *et al.*, 2003a; Van Hoey *et al.*, 2004). Remarkably, *Scolelepis squamata* occurs high up in the intertidal zone, like e.g. in Morocco (Bayed *et al.,* 2006) but not in the Netherlands (Janssen & Mulder, 2005). Lower in the littoral zone species richness is higher, but abundances are lower than in the upper intertidal community (Degraer *et al.*, 2003a). Typical species of the lower littoral zone are *Nephtys cirrosa, Donax vittatus* and several bristle worms like *Spio* spp. and *Spiophanes bombyx*. In the lower littoral, species are encountered which can withstand short exposure to the air, but they reach optimal conditions and thus higher numbers in the infralittoral (Degraer *et al.*, 1999a). The fact that cross-shore zonation can be observed more clearly on dissipative beaches (Jaramillo and McLachlan, 1993; McLachlan and Jaramillo, 1995), is confirmed. Zonation patterns of several species are subjected to seasonal oscillations: some species exhibit seasonal migrations, being located lower on the beach in winter (e.g. Degraer *et al.*, 1999a). Total biomass of Belgian sandy beach macrobenthos has been determined only once (ash free dry weight = AFDW) with values of 40 to 800 mg AFDW/m² (Elliott *et al.*, 1997). An initial increase below the high water mark was observed, followed by a decrease until below mid tide level and finally another yet slow increase towards the infralittoral zone.

Macrobenthic organisms represent a major food source for birds (see infra) and epibenthic fish (e.g. Plaice *Pleuronectes platessa*) and macro-crustaceans (e.g. Brown shrimp *Crangon crangon*) (Beyst *et al.*, 1999). A number of flatfish (e.g. Plaice *Pleuronectes platessa*) depend on intertidal infauna during their juvenile stages: the littoral zone acts as a nursery for these species. Juvenile flatfish migrate with the incoming tide towards the littoral zone, thus escaping predators from deeper zones and feeding there (Beyst *et al.*, 1999). This is also the case for hyperbenthic organisms like mysids (Mysida) (Beyst *et al.*, 2001a). For several fish species and species of the hyperbenthos, the intertidal surf zone also serves as a migration route between nursery grounds or between the nursery ground and the deeper marine environment (Beyst *et al.*, 2001a, 2001b). Both flat, ultradissipative beaches and intermediate beaches are inhabited by high numbers of flatfish, while the highest species richness seems to be reached on intermediate beaches (Beyst *et al.*, 2002a, 2002b). Lower species richness on the more reflective beaches along the eastern coast might be due to the influence of the nearby estuary of the Westerschelde. Several Belgian beaches, especially along the western coast, have runnels and ridges. The runnels stay submerged over a longer period of time and contain high levels of organic matter. They contain a benthic fauna which resembles infralittoral fauna (Boulez, 2002), e.g. high densities of *Spio* spp. Both in abundance and in diversity, the fauna exceeds that of neighbouring sand banks. Within beach benthos research, runnels were generally neglected.

From the Belgian foreshore, only data on macrobenthos are available. In contrast to the littoral zone, with only one typical macrobenthic community, several communities can be found on the foreshore. Four subtidal macrobenthic communities (*Abra alba – Mysella bidentata*, *Nephtys cirrosa* and *Ophelia limacina - Glycera lapidum* communities and *Macoma balthica* community (Degraer *et al.*, 2003b; Van Hoey *et al.*, 2004) are all found in specific sediments. These communities are, however, not homogeneously distributed on the Belgian foreshore. East of Oostende, the species poor, but highly abundant *M. balthica* community (87% of sample stations) dominates, while it more or less lacks west of Oostende (7% of sample stations) (Degraer *et al.*, 2003b). Sample stations west of Oostende are rather evenly distributed over the three other subtidal communities. The species and abundance richest *A. alba – M. bidentata* community is dominant at the Western Coastal Banks. Within the latter community, many bivalves can be found (e.g. *A. alba*, *Spisula subtruncata* and *Tellina fabula*). In view of their role as food for species such as common scoter *Melanitta nigra* and Atlantic cod *Gadus morhua* (Degraer *et al.*, 1999b) and the high species richness and abundance of macrofauna (Van Hoey *et al.*, 2004), this community has been put forward as the ecologically most valuable community of the Belgian Continental Shelf (Degraer and Vincx, 2003).

Thus, more or less decreasing ecological macrobenthic value can be observed from west to east.

The dry beach and the strand line are most subjected to the influence of coastal tourism. Hence, the interstitial dry beach fauna of tourist beaches is characterised by only one or just a few extreme colonisers and taxonomically closely related species (Gheskiere *et al.*, 2005a, b). The benthic fauna in the littoral zone mainly suffers from coastal defence and tourism. On the Belgian foreshore, human activities are widely distributed (Maes *et al.*, 2000). Kerckhof and Houziaux (2003) offer an overview of the major threats the subtidal marine fauna of the Belgian Continental Shelf are facing, specifically for benthic fauna: (1) beam trawl fisheries, (2) dredging and dumping of dredged materials, (3) introduction of invasive species, (4) coastal defence, (5) eutrophication and (6) pollution. While not really as prominent in the nearshore shallow waters as less damaging types of fisheries, the impact of beam trawl fisheries on the benthic life is significant. Beam trawl (shrimp) fishery intensity is very high on the Belgian Continental Shelf and is treated as a real threat to sensitive benthic habitats and communities. Several reef building (and thus habitat structuring and biodiversity elevating) organisms, like oysters (oyster banks) and the sand mason worm *Lanice conchilega* ("*Lanice* reefs"), as well as larger, habitat structuring epibenthic species of the coastal zone, like sponges (Porifera), are under serious threat as a consequence of beam trawl fisheries. By creating new habitats (hard substrates) and altering the original habitats, coastal defence has had a drastic impact on the benthos of the Belgian foreshore. The impact on the original resident fauna is, however, poorly known. Finally, eutrophication and pollution (oil, solid waste, …) are also widely distributed problems on the Belgian Continental Shelf and they have an overall negative impact on the entire marine ecosystem.

AVIFAUNA

The supralittoral zone is important as a nesting area for birds. Mainly Kentish plover *Charadrius alexandrinus* and little tern *Sterna albifrons* can be expected to breed here. Both species are in the Red Data List as breeding birds threatened with extinction (Vermeersch *et al.*, 2004). During the twentieth century, most Belgian beaches became unsuitable for nesting of coastal birds because of anthropogenic pressure (mainly destruction of nesting habitat and disturbance) (Stienen and Van Waeyenberge, 2004). In 1954, 45 breeding pairs of Kentish plover where observed on Belgian beaches (Raes, 1989), while this species was almost absent from 1990 onwards. Only in 1994-1996 – in absence of high tourist pressure – a few pairs of Kentish plover nested on the Lombardsijde beach and at De Panne (Devos and Anselin, 1996; Anselin *et al.*, 1998). Also the Zwin nature reserve held some pairs (always < 4) during the 1990s. During the onset of the twenty-first century, breeding numbers in coastal environments dropped to less than 3 pairs (Vermeersch *et al.*, 2004; 2006). In the middle of the past century, several little terns were nesting on the beaches between Koksijde and Oostduinkerke (maximum of 30 pairs in 1951 and 1952, disappeared in 1962), at Lombarsijde (maximum of 11 pairs in 1959, disappeared in 1960) and at Knokke-Heist (maximum of 75 pairs in 1939, disappeared in 1957). In the Zwin nature reserve, numbers increased in the 1960s due to nature management (maximum of 15 pairs in 1962, disappeared in 1964). The last nesting in a natural habitat dates back to 1973 (Van Den Bossche *et al.*, 1995; Seys, 2001). However, with the development of the port of Zeebrugge in the 1980s vast areas of sandy, sparsely vegetated and relatively undisturbed land were created. These mimicked natural processes in coastal areas and attracted large numbers of coastal breeders (Stienen and Van Waeyenberge, 2002; 2004; Stienen *et al.*, 2005). The distribution of both

Kentish plover and little tern is now limited to the Zeebrugge port and the adjacent reserve “Baai van Heist” (Courtens and Stienen, 2004; Stienen *et al.*, 2005). In Zeebrugge-Heist, maximum numbers amounted to 108 and 425 pairs respectively for Kentish plover and little tern. A similar increase was noted in the port of Antwerp (max. 18 pairs; Vermeersch *et al.*, 2006). The supralittoral on Belgian beaches also functions as resting and foraging area, mainly in winter and during migration. At high tide, most gulls and waders use the supralittoral to rest or as a place to gather before moving to high water roosts (herring gull *Larus argentatus* and black-headed gull *L. ridibundus* but also common gull *L. canus* and lesser black-backed Gull *L. fuscus*). The most important high water roosts are located near larger tidal flats and on groynes. Tidal flats (reserves “IJzermonding”, “Baai van Heist” and until recently the port of Zeebrugge) are, apart from being used by gulls, also used by foraging wading birds (oystercatcher *Haematopus ostralegus* and dunlin *Calidris alpina*, smaller numbers of grey plover *Pluvialis squatarola*, ringed plover *Charadrius hiaticula* and common redshank *Tringa tetanus* - Speybroeck *et al.*, 2005). High tide roosts of turnstone *Arenaria interpres*, purple sandpiper *Calidris maritima* and sanderling *Calidris alba* are mainly on groynes along the midcoast (Engledow *et al.*, 2001; Becuwe *et al.*, 2006). Numbers of turnstone and purple sandpiper initially strongly increased after 1975 along with the increased use of hard substrates for coastal defence (Becuwe *et al.*, 2006). Turnstones feed in the supralittoral zone on strand line material (Smit and Wolff, 1981; Becuwe *et al.*, 2006).

In the intertidal area, standardized counts of wading birds at low tide were carried out within four recent studies (Engledow *et al.*, 2001; Stuer, 2002; De Groote, 2003; Speybroeck *et al.*, 2005). Many bird species feed on intertidal macrofauna. On Belgian sandy beaches, this applies primarily to gulls and wading birds, the latter being mainly oystercatcher, dunlin and sanderling (Engledow *et al.*, 2001; Stuer, 2002; Speybroeck *et al.*, 2005). During the winter of 2000-2001, approximately 1450 oystercatchers and up to 350 sanderlings were present along the Belgian coast (Engledow *et al.*, 2001). On average, more than 50% and 70%, respectively, were counted on the beach. During winter on sandy beaches, oystercatchers feed nearly exclusively on shellfish (Camphuysen *et al.*, 1996, Hulscher, 1996; Zwarts *et al.*, 1996), whereas dunlin typically feeds on oligochaetes and polychaetes (Kelsey and Hassall, 1989; Mouritsen and Jensen; 1992; Nehls and Tiedemann, 1993). They preferably feed on easily penetrable, wet substrates along the edges of gullies and along the low water line (Stuer, 2002). Sanderling feeds in the swash zone and are partly depending on the presence of the polychaete *Scolelepis squamata* as prey, but also various other prey washed ashore (Smit and Wolff, 1981; Mooij, 1982; Dankers *et al.*, 1983; McLachlan, 1983; Glutz von Blotzheim *et al.*, 1984; De Meulenaer, 2006). Among the gulls, common gull and black-headed gull frequently forage on worms and shrimps in the littoral zone, around the high tide mark and in puddles and pools of stagnant water; other species of gulls (like great black-backed gull *Larus marinus*) depend much more on infralittoral food (Spanoghe, 1999; Engledow *et al.*, 2001; Stuer, 2002). Gulls also feed on stranded dead animals and on food left behind by man (Engledow *et al.*, 2001; Stuer, 2002). First in 1989 and 1990 and later from 1998 onwards, total counts of wintering gulls were executed (Spanoghe and Devos, 2002). The total number of gulls varied from about 7.000 to 32.000 individuals. A count executed in summer suggested that numbers are much lower then (about 6.000 individuals). Speybroeck *et al.* (2005) found peak numbers of gulls during autumn migration and a low during the breeding season. The herring gull is the most common species (40-70 %), black-headed gull is second (13-42%). The common gull, lesser black-backed gull and great black-backed gull mostly make up less than 10% of the total number of gulls (Spanoghe, 1999; Spanoghe and Devos, 2002). In the past decade, common tern *Sterna hirundo* and sandwich tern *Sterna sandvicensis* made use of both supralittoral and littoral zones in and around the harbours of Zeebrugge, Oostende and Nieuwpoort to roost but also to gather before and after the nesting season (Speybroeck *et al.*, 2005).

The shallow waters of the Belgian coast are of international importance for a number of seabirds (Seys, 2001; Van Waeyenberge *et al.*, 2001; Stienen *et al.*, 2002), of which most species can be called coast-dependent, at least in a specific season (common scoter *Melanitta nigra*, crested grebe *Podiceps cristatus*, little gull *Larus minutus* and terns (little tern, common tern and sandwich tern). Internationally of less importance but with a strong coastal connection are black-headed and common gulls. All these species are dependent on shallow waters and the associated food resources, which are within the first 10 kilometres from the shore. Only a minor portion of most species strongly depends on the actual foreshore zone. For the common scoter, the western coast is of primary importance, namely the areas “Trapegeer, Broersbank, Potje” and “Stroombank, Nieuwpoortbank, Oostendebank” often harbour high numbers in winter (especially February-March). While the former area was important during the 1980s, the importance of the latter increased from the 1990s onwards. Peak numbers occurred in 1994 (15475 in Belgian waters). Common scoters depend on the presence of small bivalves (*Spisula* spp., nowadays probably *Ensis* spp.) at shallow depths. They are extremely sensitive to disturbance (e.g. by shipping and air traffic) and oil pollution (Camphuysen, 1998). Shell fisheries (beam trawls) pose a threat to the species (Degraer *et al.*, 1999b). Crested grebes are winter visitors (mainly December-February) and they are tied to the coast (in general within 15 km offshore). Major areas are situated along the western coast (around “Westdiep”), further east (Middelkerkebank, Oostendebank, Wenduinebank) and on “Vlakte van de Raan” along the eastern coast. From 2000 onwards, numbers residing in Belgian coastal waters have increased, with peak numbers of 12700 individuals (corresponding to 2.6% of the biogeographical population) counted in January 2003. This species is strictly piscivorous. Grebes are not very sensitive to disturbance but due to their swimming lifestyle they are sensitive to oil pollution, although remarkably low numbers stranded along the Belgian coast during the Tricolor oil spill (Stienen *et al.*, 2004). Little gulls reach highest numbers during migration (March-April and September-October). Their distribution shows strong seasonal fluctuations. In autumn, they are most tied to the coast. Highest numbers are then along the eastern coast (especially Zeebrugge harbour) but elevated concentrations occur also around the harbours of Oostende and Nieuwpoort. At maximum, 3670 individuals were counted in Belgian waters (4.4% of biogeographical population), but Seys (2001) estimated that a much larger proportion of the biogeographical population (up to almost 100%) may use the Belgian coast as a migration corridor. Little gulls are not very sensitive to disturbance, but because they rest at sea during night they may be sensitive to oil pollution. The sandwich tern is both a summer visitor (nesting bird at Zeebrugge) and a passage migrant. The species is present in Belgian marine waters from April to November. The main feeding grounds of this species are scattered along the western coast (Westdiep, Smalbank), the central coast (Stroombank and western Wenduinebank) and the eastern coast at the “Vlakte van de Raan” and the “Scheur” (Seys, 2001; Del Villar d’Onofrio, 2005). Sandwich terns are visual predators, which feed on a limited number of fish species

(Stienen *et al.*, 2000). Thus, they are sensitive to water pollution with accumulating toxic substances and possibly also to elevated turbidity (Brenninkmeijer *et al.*, 2002). Breeding numbers peaked in 2005, when 4067 pairs (7.2% of the biogeographical population) nested in the port of Zeebrugge (Stienen *et al.*, 2004, Everaert and Stienen, in press). An estimated 67% of the biogeographical population uses the Belgian coastal waters as a migration corridor (Seys, 2001). The common tern is both a summer visitor (nesting at Zeebrugge) and a migrant, present from April until November. Highest numbers are reached at Zeebrugge port. Outside the port itself, mainly the coastal waters west of Zeebrugge the harbour (Wenduine bank and surroundings) and the southern part of "Vlakte van de Raan" are important foraging areas (Seys, 2001; Del Villar d'Onofrio, 2005; Courtens *et al.* 2006). In Zeebrugge port, breeding numbers peaked at 3052 pairs in 2003 (4.8 % of biogeographical population), but numbers of migrants passing along the Belgian coast may very well exceed 50%. Common terns are also sensitive to the presence of accumulating toxic substances and collisions with wind turbines (Becker *et al.*, 1998; Thyen *et al.*, 2000; Everaert and Stienen, in press). Unlike sandwich terns, they are often found foraging in turbid waters and are probably less sensitive to elevated water turbidity. For little tern mainly the Zeebrugge harbour and the surrounding area within a 2 km radius are of importance. Like the other two tern species, they are top predators that are sensitive to pollution of accumulating substances. A lower transparency of the seawater may have a negative effect on the feeding success of this visual hunter. All of the mentioned tern species are sensitive to changes in the abundance of their prey fish. This may lead to large fluctuations in breeding success and to changes in the size of their populations (Stienen, 2006). An overview of threats coastal nesting birds are facing in northwestern Europe, is given by Meininger and Graveland (2002). Important causes for loss of nesting grounds on beaches for terns and plovers in Belgium are disappearance of the grounds themselves, in part as a consequence of industrial development and the construction of bungalow parks (Arts *et al.*, 2000; Stienen *et al.*, 2005) and the loss of natural dynamics in these areas. Recreation also poses a serious threat on nesting areas, leading to decreased breeding success, lowered densities and shrinking global distribution (Pienkowski, 1993; Schulz and Stock, 1993). Seabird populations are often limited in size by the availability of their food (Birkhead and Furness, 1985; Croxall and Rothery, 1991). Changes in tern population have been linked to fluctuations in food resources, mainly fish of the families of Clupeidae and Ammodytidae (a.o. Monaghan *et al.*, 1989; Vader *et al.*, 1990; Brenninkmeijer and Stienen, 1994; Meininger *et al.*, 2000, Stienen, 2006). Thus, excessive fisheries of prey species can pose a serious threat (Furness and Tasker, 2000). Other threats are predation by mammals and gulls as well as competition for breeding space between gulls and terns (a.o. Thyen *et al.*, 1998; Quintana and Yoro, 1998; Meininger and Graveland, 2002; Becker and Ludwigs, 2004). Toxic components entering the food web and being accumulated in eggs may affect coastal breeding birds (Becker *et al.*, 1998; Thyen *et al.*, 2000).

Figure 10 provides a schematic image of the spatial distribution and trophic role of some taxa.

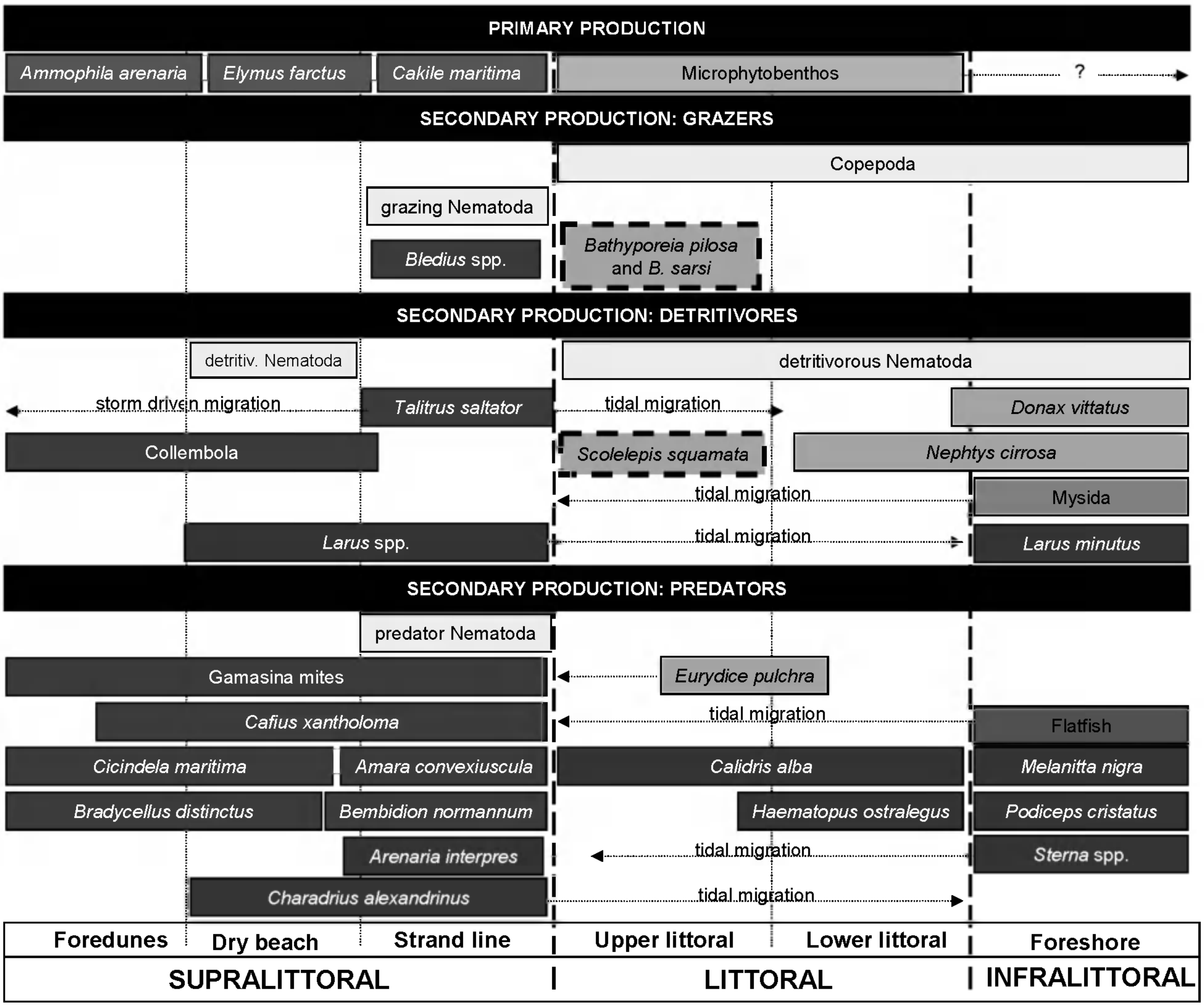


Figure 10. Productivity allocation on Belgian beaches represented by some abundant taxa. Data on Nematoda of the foredunes is lacking. The studied key species (Chapters 3-6) are indicated by boxes with bold, dashed borders.

The scheme demonstrates that the strand line present a rather sharp boundary between the marine and terrestrial environment, with little biological interaction across it. Stranded wrack presents an indispensable input of organic matter for typical species of fauna and flora, yet it is a more or less stand-alone system, with little connection to intertidal biota. Exceptions towards this boundary are the highly mobile avifauna and some venturing arthropods (at low tide). The boundary of the littoral and infralittoral parts is far less sharp, e.g. the gradual transition from lower intertidal macrobenthic community to foreshore communities and the tidal migration of flatfish.

In the supralittoral zone, vascular plants perform primary production, whereas microphytobenthos does so in the littoral zone and perhaps even further down. The importance of the latter for the zoobenthos is not known, although *Bathyporeia* species are said to feed on epipsammic diatoms. Detritivory is widespread: *Talitrus saltator* is a key decomposer of wrack in the supralittoral zone, and most macrobenthic fauna in the littoral zone are detritivorous as well. Very little is known about biological interactions on Belgian sandy beaches and this certainly offers perspective for future research.

While species richness and biodiversity may be lower on Belgian beaches than in some other ecosystems, each biological component plays a key role in the functioning of this highly productive ecosystem, specifically adapted to life in a dynamic physical environment. Sandy beaches can no longer be regarded as biological deserts. Therefore, management of beaches should involve more caution than is often the case. Even though a significant proportion of the beach inhabiting organisms is adapted to the naturally high environmental stress of tides, waves and winds, this adaptation has its limitations. Several aspects of recreation, beach management and commercial activities are the main threats that sandy beaches are facing along the Belgian coast.

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